High Voltage Materials Research Overview and Current High Voltage Test Capabilities and Build-Up

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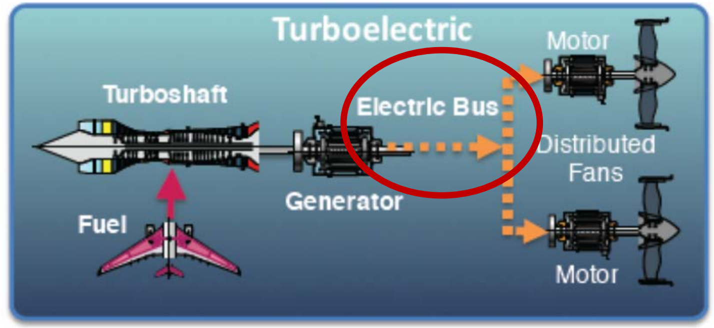
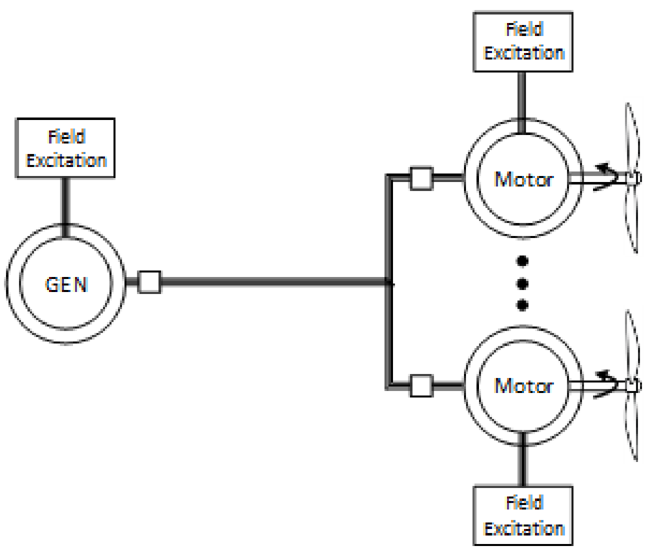
Multifunctional Materials Team Project Review

TRANSFORMATIONAL TOOLS AND TECHNOLOGY

Lightweight High Voltage Power Transmission



High Voltage Hybrid Electric Propulsion (HVHEP) Architecture



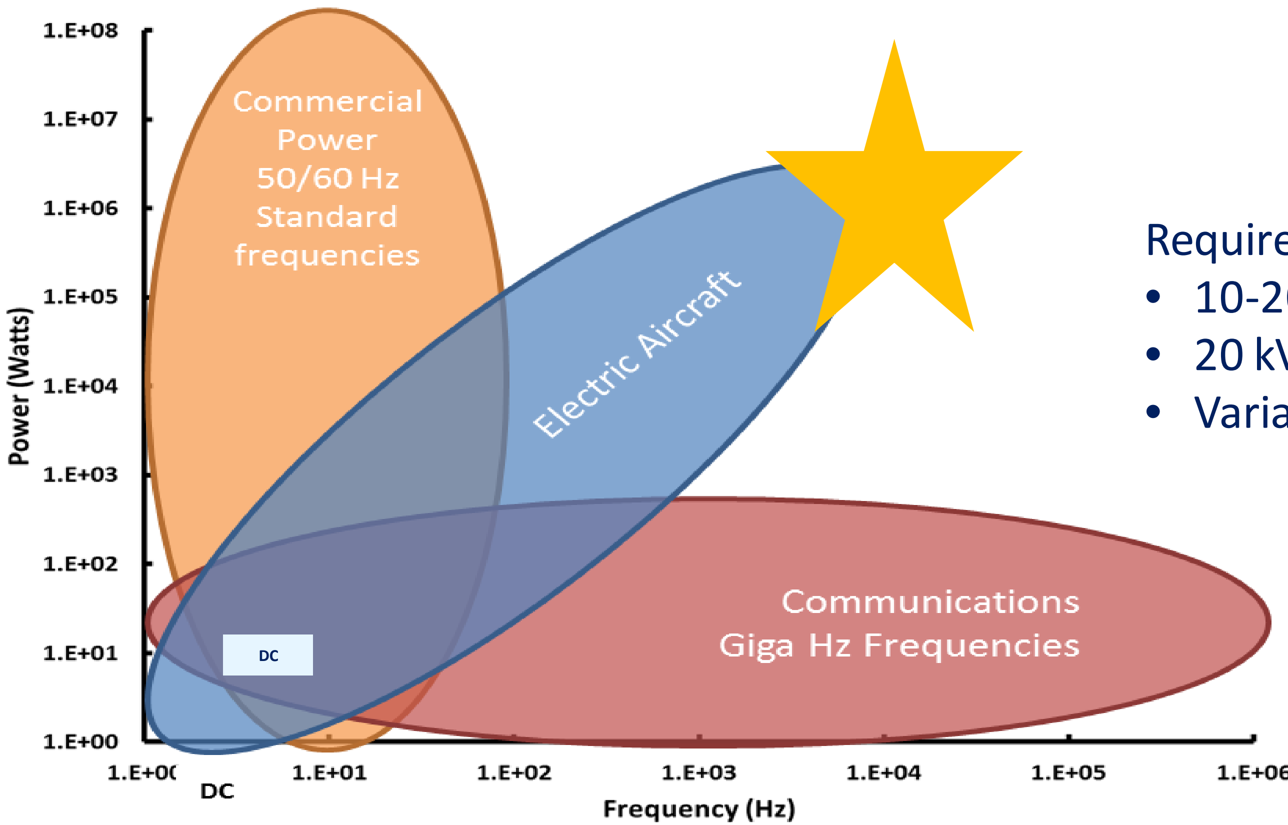
Future Aircraft will require ~10-20 MW power distribution

High Voltage, 3-Phase AC,
Variable Frequency 400 Hz to 4000 Hz
V_{max} = 20 kV Design for V > 41 kV

Unique Application Space

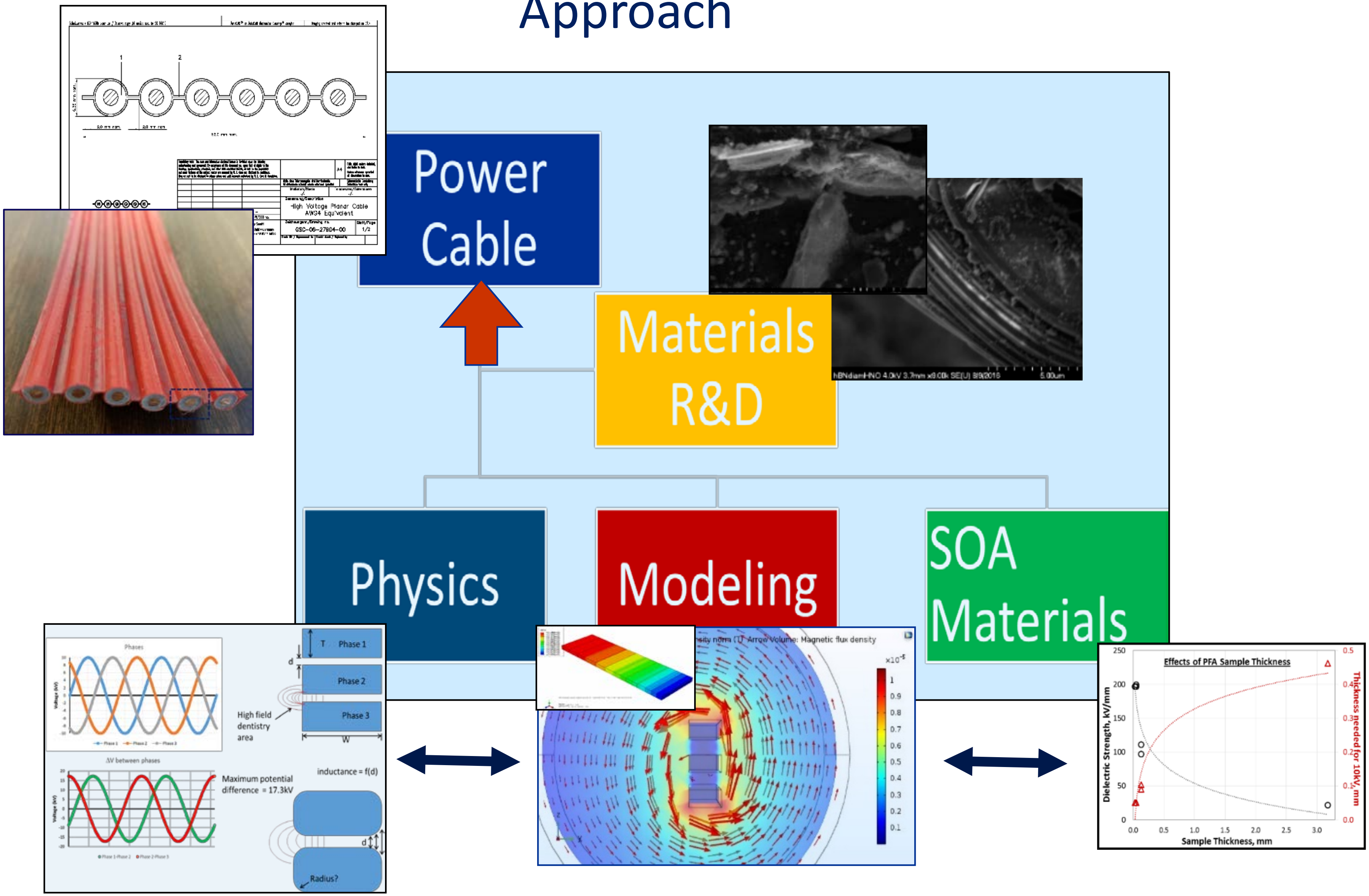
Notional Current Technology Description

Combination of power and frequency make this a unique application space.
Current high voltage cable technology is not suitable for high altitude operation.

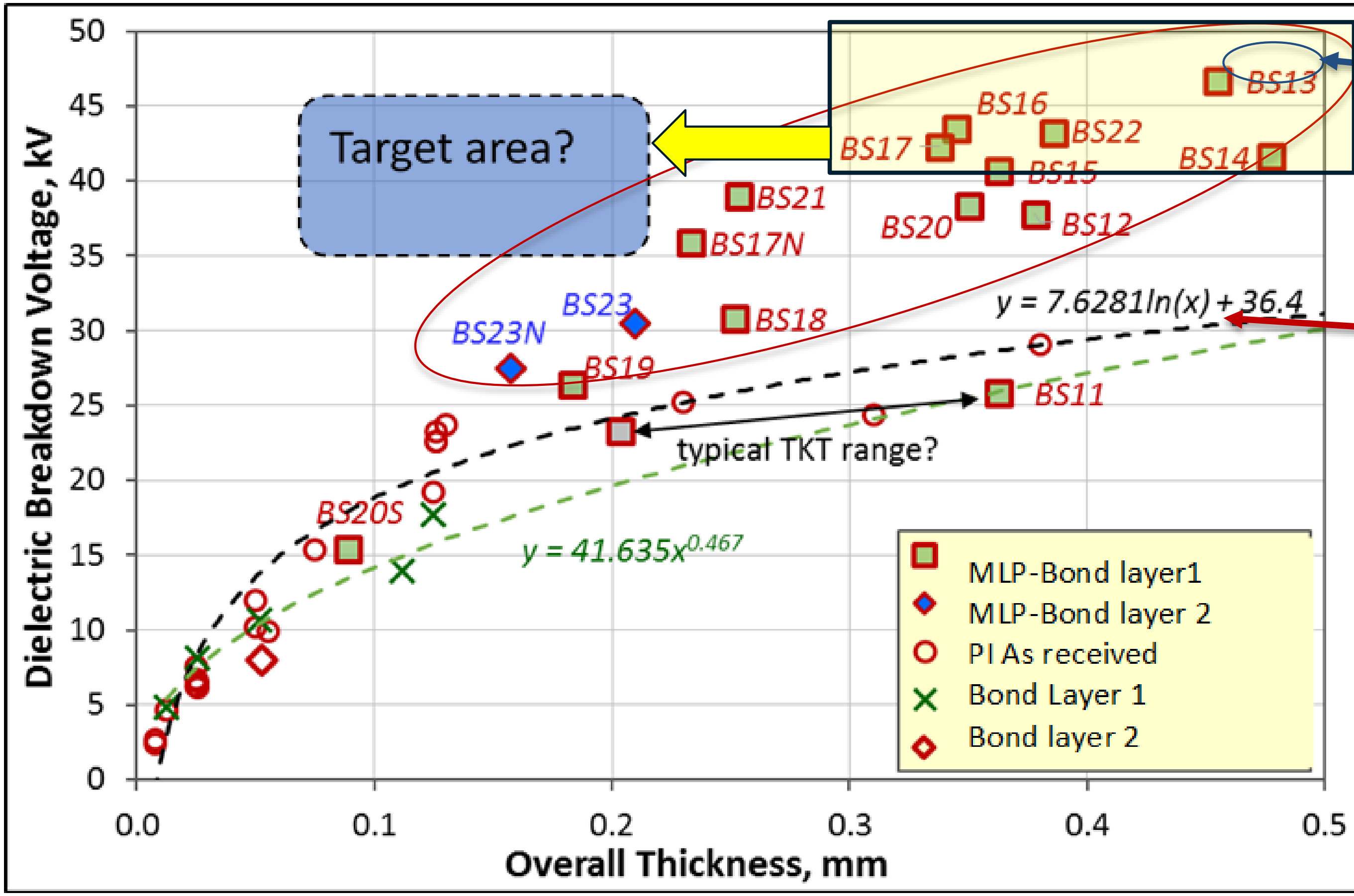


Requirements
- 10-20 MW power cable
- 20 kV_{ac} , 3-phase
- Variable ƒ = 400-4000 Hz

Approach


High Voltage Planar Cable
AWG4 Equivalent
GSC-06-27804-00
Power Cable
Materials R&D
Physics
Modeling
SOA Materials
Phases
Phase 1
Phase 2
Phase 3
High field dentistry area
ΔV between phases
Maximum potential difference = 17.3kV
inductance = f(d)
Radius?
Effects of PFA Sample Thickness
Dielectric Strength, kV/mm
Thickness needed for 10kV, mm
Sample Thickness, mm

SOA and Developed Insulation Material Testing



V_b = ~ 46.7 kV

SOA Equivalent thickness

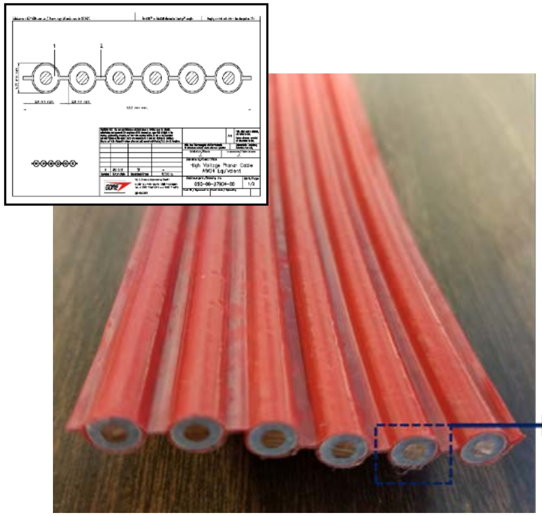
$V_{b\text{-}SOA}$ = ~ 30 kV

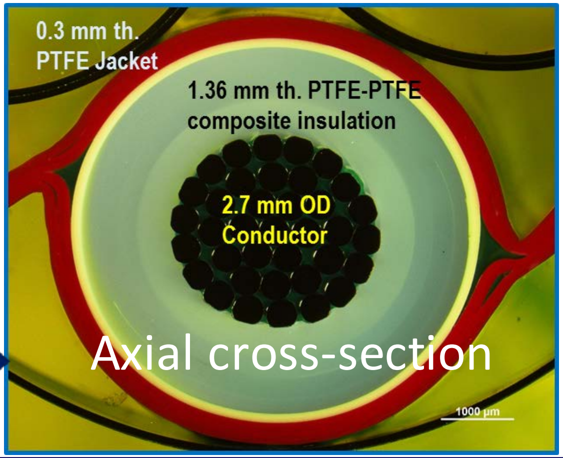
Equivalent V_b of PI Insulation would have a thickness of 3.85 mm compared to less than ~0.46 mm thickness.
~86% decrease in insulation thickness

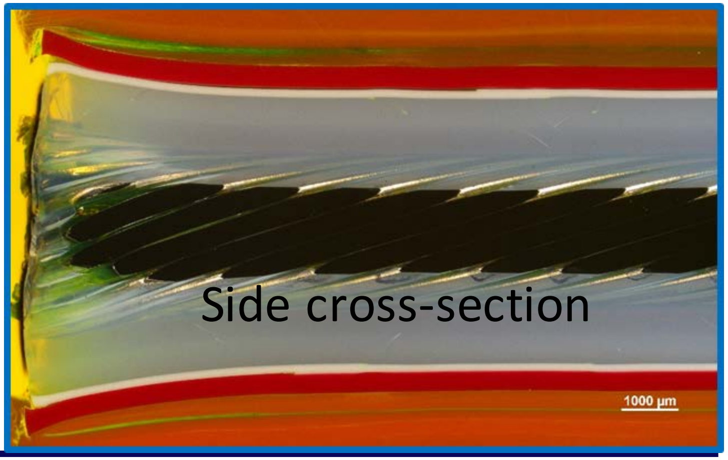
Industry Manufactured SOA *Experimental* Cable

Test results by GORE: The cable without the PTFE jacket (RED color) showed break down voltage of ~ 39 kV, with PTFE jacket break down voltage dropped to ~ 29 kV.

- Evaluation GORE cable: designed for 0.25 megawatt at 15 kV (but rated to 40 kV), -80 °C to >260 °C service temperature
- Received 30 m conductor : AWG 10 (37 mm x 0.404 mm) NPC (Nickel plated Cu) UNILAY, Stranded copper wire w/o fittings, AWG 4 equivalent → to be used for testing and fabricating the a comparable cables using in-house developed insulation system.

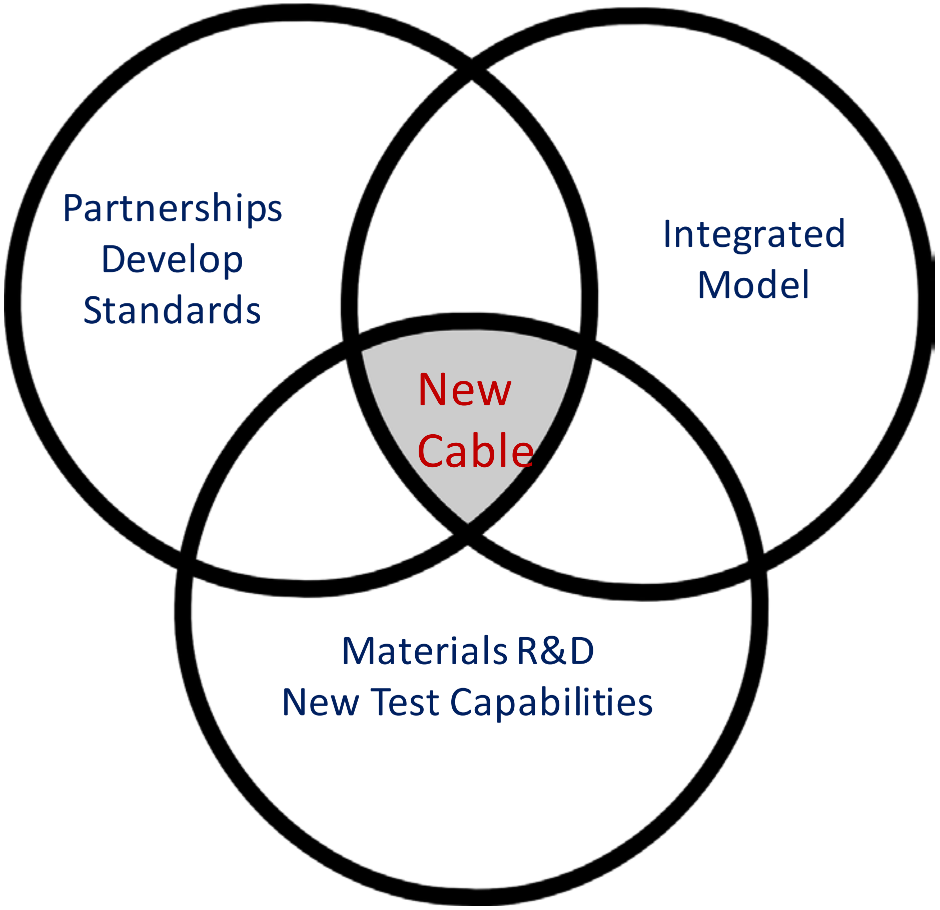






Key Findings: HVHEP Convergent Aeronautics Solutions Task

- Need New method and Test Chamber: Current Test Methods may not be sufficient
- Materials Development + Modeling Tools
  - → Best Design
- Responsive to Outside Material Technology Development
  - Corona resistant materials
  - 2-D EMI Shielding
  - Composite conductors
  - Dielectric insulation
- Decrease materials stresses
  - → increase performance life
- Foster collaborations with industry and universities
  - Industry Provided Integration Paths
  - University led Materials Research
  - Develop Testing Standards



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HIGH VOLTAGE TESTING CAPABILITIES AND BUILD UP

T^3 Project Objectives Related to This Workshop

- Draft Standard Test Method of High Altitude High Voltage Power Transmission Insulation Materials/Cables (5 years)
- Build HV Multi-stress Environmental Test Chamber Capability (2-3 Years)
- Demonstrate a 1kV - 5 kV Power Transmission Cable (2-5 Years)

Dielectric Breakdown Test Rig

Eaton High Voltage Test Set
Located at NASA GRC 106:B10

Dielectric Test Rig Specifications

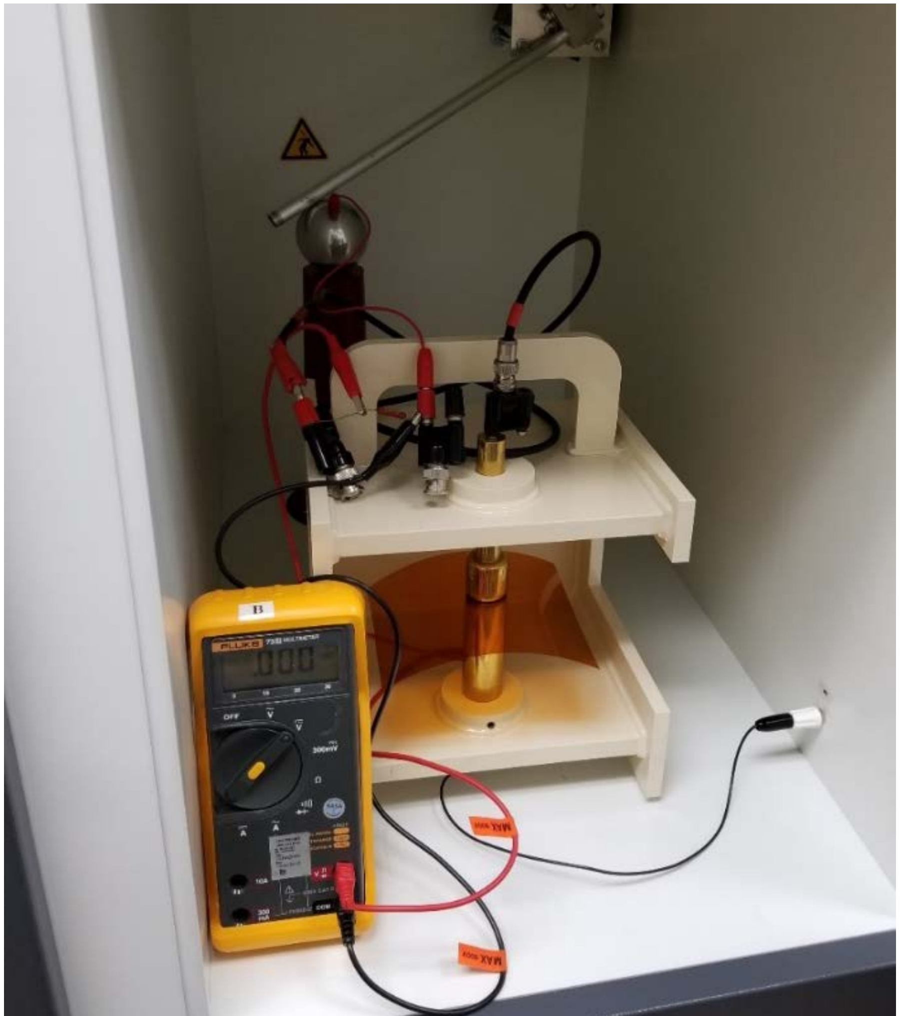
		AC	DC	
Output voltage AC :	Vmax.	60.00	84.84	kV
	Vmin.	1.800	2.545	kV
Regulation:		+/-0.4	0.57	kV
Resolution:		0.017	0.024	kV
Ramp Rate:	max.	5.500	7.777	kV/s
(Average speed)	min.	1.100	1.555	kV/s

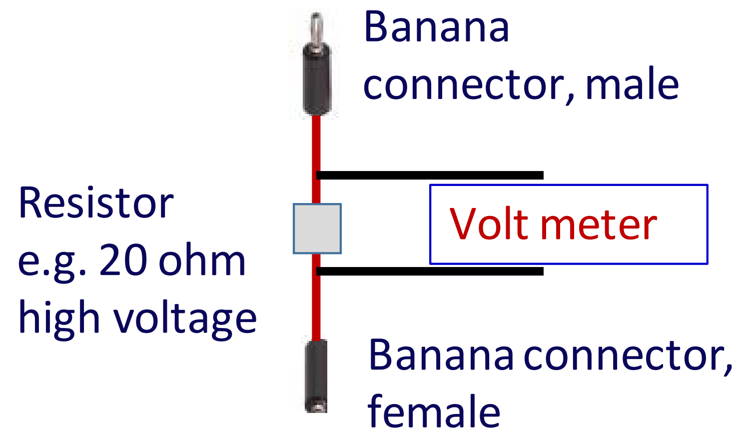
Electrode Test Fixtures

Seven electrode test fixtures (T1-T7) available according to ASTM D149-09 for Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies

Operates at 50 or 60 Hz
Need Higher Frequency Capability

Corona Inception Voltage Measurements Using Dielectric Test Rig





→ Built a separate unit that can be simply connected to the outlet side of the test fixture, then run, without changing or modifying the dielectric test system

→ Monitored micro-voltage changes on Voltmeter via video as a function of time

High Voltage/Frequency Permittivity Test Rig

Oscilloscope – monitors input and output

aixACCT computer & controller

Agilent 4294a Impedance spectrometer
40 Hz to 110 MHz

Trek high voltage amplifier
1 V to 10 kV

Electrode is placed in beaker and submerged in oil

Electrode

Small sample testing and Phase 1 build-up model using small chamber

Environmental Chamber for Temperature Cycling and Aging of Insulation/Coupons

Chamber with door removed

Chamber with door installed

- Two Chambers:
  - 12”W x 9.75”H x 10.25”D (0.7 ft^3)
  - 20”W x 12”H x 16”D (2.2 ft^3)
- Stress:
  - Thermal (-190 °C to +300 °C)
  - Electrical (1100 V at mA’s DC, AC)
- Built-in Controller:
  - Temp Rate: 0.01 to 30 °C/min
  - Dwell Time & # of Cycles
- Air Flow: 120 ft^3/min (vertical)
- Four 1” Diameter Ports
  - Power Cabling
  - Instrumentation Wiring

Program Support: NASA Electronic Parts & Packaging (NEPP) and Solar Electric Propulsion Project (SEP)

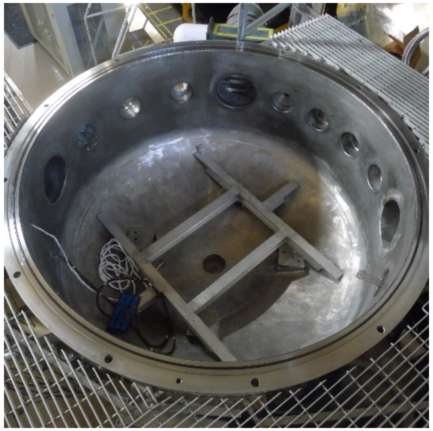
Hipotronics High Voltage Power Supplies

- **Power Supplies:**
  - AC: 12.5 - 15.5 kV
  - DC: 15 – 40 kV
  - Dielectric breakdown
  - Partial discharge

- **Electrodes**
  - ASTM standards
  - Brass & stainless steel
  - Flat & needle point

Phase 2 Multi-Stress Environmental Chamber Build Up Objectives

- Begin design work for an environmental test chamber that can simulate an inflight environment for testing electrical power distribution bus bars and/or cable coupons with an emphasis on corona aging with thermal and mechanical stress.
  - Pressure
  - Temperature
  - Vibration
  - Ionizing radiation
  - Ground plane fixed & movable (flat, round, pointed)



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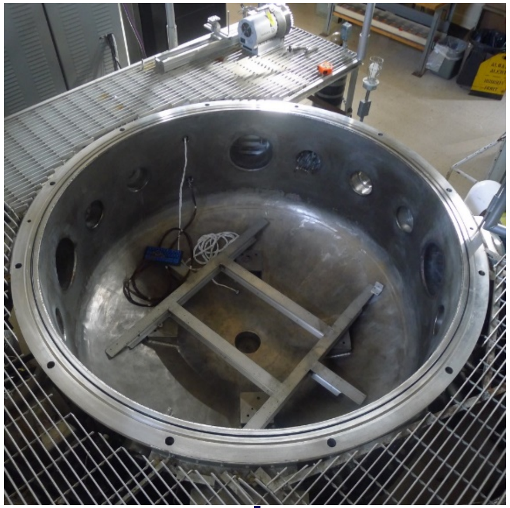
Available Environmental Chamber for High Voltage Test Rig



Advantages

- Footprint established
- Power Input established
- Plenty of room to work with
- Facilities pays to restore and maintain chamber vacuum system
- System will be dedicated to High Voltage Testing
- No Cost for large chamber

Disadvantages:

- Chamber is much larger than needed
- Facilities Operator Cost
- Funding Availability

Multi-Stress Environmental Test Chamber Build Up Concepts

Low Voltage Function Generator

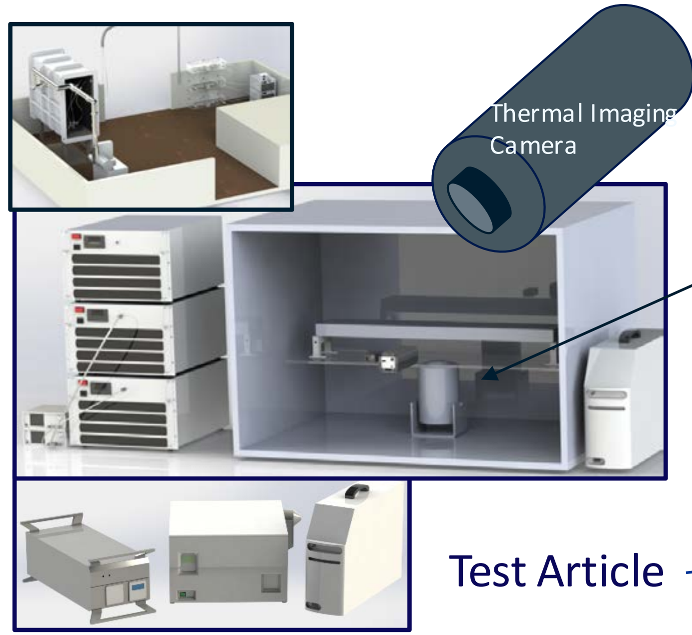
$V_{in} = \pm 10$ V
$Ƒ_{in}$ up to 2 MHZ

Trek Model 4010A

Trek High Voltage Amplifier

Output

$V_{out} = \pm 40$ kV
$Ƒ_{out}$ up to 2 MHZ



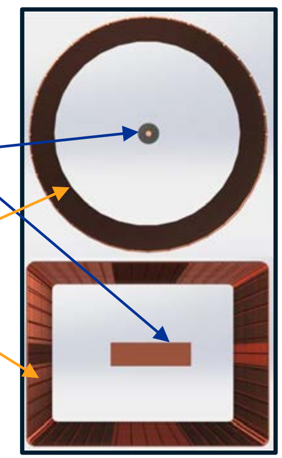
mechanical vibrations

Mass Spec System

Inside Chamber Front View

Test Article

Metal mesh



Conformal metal meshes with test article profile.

Environmental chamber
-60 °C to +300 °C

Discussion Questions

1. Are there any recommendations that might have been missed in the environmental chamber build-up concept?

2. Do we need to incorporate vibration testing in the chamber or as a separate test?

3. Should humidity be considered separately?

Thank You